difference is only one of 3·78 per cent., and the mean difference did not exceed 34 calories on 34,462, amounting to 0·1 per cent. only. It may therefore be concluded that the present calorimeter has proved itself very accurate for the determination of the heat produced by the combustion of a given volume of hydrogen gas; and, consequently it can be accepted as equally reliable for the correct estimation of the heat radiated from the human body or from that of a fairly large animal.

"An Experimental Enquiry into the Heat given out by the Human Body." By W. MARCET, M.D., F.R.S., and R. B. FLORIS, F.C.S. Received March 10,—Read April 28, 1898.

(From the Physiological Laboratory of University College, London.)

Dr. Marcet's calorimeter having been fully described in the previous paper, the present conjoint authors now submitted themselves to experiment, one of them remaining shut up in the chamber, usually for the space of an hour, while the other was engaged outside to regulate the temperature of the chamber and note the readings of the thermometers.

When breathing was carried on inside the calorimeter, it might be thought that the air of the chamber became too full of CO_2 or too deficient in oxygen for the purposes of respiration. Such, however, was not the case, and no discomfort whatever was experienced in the course of an hour's incarceration. It is easy to calculate from a consumption of, say, 26·488 grams of O per hour that supposing the calorimeter to be absolutely air-tight, a condition which was not actually realised, there would be a fall of oxygen, after one hour spent in the calorimeter, equal to a reduction of pressure from 760 mm. to 668 mm., and this would correspond to an elevation of about 7000 feet (2135 metres) above the sea level. Such an altitude would certainly not be trying to the respiration.

The experiment was carried out as follows in every instance:—

Previous to entering the chamber the subject of the experiment sat down in the laboratory to rest, in many instances taking his temperature, sublingual, with a clinical thermometer.

In the meantime a weight of ice varying between 10 lbs. and 15 lbs. (4·5 to 6·8 kilograms), according to circumstances, was cut into blocks about 2 or 3 inches diameter, and placed in the ice holder, where the blocks were disposed as much as possible in a position to allow the air from the agitator to circulate freely between them. A temporary receiver for the water from the melting ice was hung to a

hook soldered to the tube delivering the ice water, for which receiver a flask of a capacity of over a litre was substituted on starting the experiment in the chamber.

When all was ready, the person under experiment stepped into the calorimeter and sat down on a wooden chair. Immediately afterwards the ice holder was hung up in the chamber to a strong hook fastened to the roof; then the tube from the upper agitator was connected with the ice holder, and the flask with a thermometer in it, previously weighed, was substituted for the temporary small receiver of the melted ice. At that very instant the stop-watch was started to register the time spent in the chamber, the door was closed and screwed down, and the two agitators were set in motion. It might here be observed that the person in the calorimeter felt no draught, as the air from the lower agitator was driven up behind him through a rose-jet, and that from the upper agitator fell in front of him on its exit from the ice holder. Indeed no sensation of cold was experienced, or any discomfort whatever, the temperature in the chamber remaining exactly the same within a few tenths of a degree centigrade throughout the experiment. In those cases where the air expired had to be collected for analysis, this was done by means of a face-piece strapped to a cap fitting the back of the head. The face-piece was supplied with a glass tube, which was taken between the lips and used for the expiration, while another tube served for the nasal inspiration from the outside of the chamber, without the intervention of any valves. Fresh air was thus inspired through the nose and expired through the mouth—a method of breathing with which we were familiar. The inspiratory tube communicated with the external air through the walls of the chambers, while the expiratory tube was connected at will either with the bell-jars or the open air. The bell-jars were suspended in such a way that the person in the chamber never knew when he was breathing into the open air or into the air holders. Three bell-jars were in use, and in many cases an india-rubber bag, faced with oil-silk, was pressed into service, so as to allow of the collection of an increased volume of expired air. The volume of air collected, though only including the air expired during from twenty minutes to half an hour, taken at intervals through the whole time, certainly gives an accurate estimation of the composition of all the air breathed while in the calorimeter, considering that the person remains in a perfect state of repose during that time, except, perhaps, for a minute on entering the chamber.

On one occasion the whole of the air expired in one hour was collected, and in that experiment it was found that the volume of air expired in half an hour, taken at different intervals of time, was proportional to the volume expired in the whole hour.

The observer, whose duty it was to read the thermometers, stood up on a stool ready to work the regulators of the dynamos, and by constant attention the temperature of the metal of the copper chamber was not allowed to fall or rise beyond about 0·3° from the initial reading.

After an hour, measured to a second with the stop-watch, a last reading of the thermometers was taken while at the same time a signal was made to the person in the chamber by showing him a light, and he immediately closed the stopcock of the tube letting the melted water into the flask. By this means the water collected was given out exactly in one hour, the agitators were stopped, and the person under experiment finally let out. As soon as the door was open, the temperature of the ice water in the flask was recorded.

The sublingual temperature when required was again taken at that time, if it had not been determined in the last few minutes of the stay in the chamber.

The next process was to weigh the flask with the ice water and thermometer, and by subtracting the weight of the empty flask and thermometer, that of the melted ice was obtained. In one hour's experiment the water from the melted ice amounted to rather over 1000 grams, but its weight varied on each occasion. The counters in connection with the agitators were now read.

This completed the data for the calculation of the calories recovered in the chamber. The calculation, a very simple one, is illustrated in the following table, which gives the particulars of one experiment taken at random :—

Illustration of the Observations and Calculations required in one Experiment.

Two preliminary Test Experiments with Agitators to determine Heat given out.

		Upper agitator.	Lower agitator.
1st counters.	Final readings ..	924,442	677,155
	Initial ,, ..	735,640	494,300
	Number of revolutions ..	188,804	182,855
2nd counters	Final readings ..	1,104,775	852,831
	Initial ,, ..	924,444	677,155
	Number of revolutions ..	180,331	175,676

	Sum of revolutions squared.	Calories found.
1st	13,813	12,527
2nd..........	12,674	12,138
Means	13,244	12,333

Experiment with Subject in Calorimeter.

		Upper agitator.	Lower agitator.
Counters	Final readings....	238,566	1,052,431
	Initial „	104,775	852,831
		133,791	199,600

133,791
199,600

$(333,391)^2 = 11,115....$

$13,244 : 11,115 = 12,333 : x$
$x = 10,355$

	Chamber.	Copper.	Annular space.
3.51 P.M.	15·30° C.	15·16° C.	15·20° C.
4.1	15·33	15·26	15·26
4.11	15·34	15·13	15·32
4.21	15·62	15·22	15·32
4.31	15·28	15·12	15·32
4.41	15·74	15·22	15·34
4.51	15·12	15·10	15·35
Difference of extremes	—0·18	—0·06	+0·15

Time spent in calorimeter, one hour.
Weight of ice water, 1309·30 grams.
Temperature of water, 9° C.

Calories found.

			Calories.
Ice water......................	1309·30 × 79*	=	103,435
Ice water......................	1309·30 × 9°	=	11,784
From air in annular space..........	69 × 0·15	=	10
From copper†	5832 × 0·06 = 350		
From air in chamber ..	214 × 0·18 = 38		115,229
			—388
	388		
Calories			114,841
Correction for agitators			10,355
Heat emitted in one hour, say, calories found			104,486

* 79 = number of calories absorbed by the melting of 1 gram of ice.

† The figures 5832 for copper, 214 for air of chamber, and 69 for air of annular space are constants obtained by multiplying the individual weights by their corresponding specific heat.

Determination of Oxygen consumed or absorbed.

130·427 litres of air expired (reduced) in 26 minutes.

	Per minute.
CO_2 found	239·0 c.c.
Surplus O absorbed	65·1
	304·1 × 1·4338 (weight of 1 litre of O)

× 60 minutes = 26·162 grams O absorbed per hour.

104,486/26,162 = 3994 calories, corresponding to 1 gram O consumed.

The first set of experiments was undertaken in order to ascertain whether in the course of an hour there is any variation in the heat given out by the same person, and, with this object in view, the heat emitted by each of us in turn was determined throughout the first and second half-hours spent in the calorimeter. It was found necessary to introduce a three-way cock into the tube delivering the water from the melted ice into the flask; this three-way cock diverted the stream at will into one or other of two flasks hanging to the tubes leading from the ice-holder.

The results obtained were as follow:—

Calories in two half-hours in succession.

	W. M.		R. B. F.	
	First half-hour.	Second half-hour.	First half-hour.	Second half-hour.
	58,781	58,551	55,444	51,395
	53,230	50,939	49,216	52,445
	55,327	52,161	49,128	53,812
	59,947	62,177	48,037	48,914
	46,644	48,954	49,540	51,905
	—	—	46,744	44,878
Means	54,786	54,556	49,685	50,558

Difference = 0·42 per cent. decrease in second half-hour on first half-hour.

Difference = 1·76 per cent. increase in second half-hour on first half-hour.

Total for the eleven experiments, 0·75 per cent. increase in second half-hour. (Calculation from total figures.)

Therefore, in the case of W. M., the mean of five experiments gave a difference of only 0·42 per cent. in the calories emitted during two successive half-hours, while, in the case of R. B. F., the mean difference of

six experiments was only by 1·76 per cent. The mean difference (from total figures) from the two persons in eleven experiments amounted to 0·75 per cent., showing that practically the mean heat emitted was the same in each of two consecutive half-hours. There were, however, differences, though usually slight, in each pair of experiments —sometimes an increase, sometimes a decrease—the reason of which is difficult to assign.

The calories given out by the various persons experimented upon were taken generally between lunch and dinner, say at a mean time of about two hours after a full luncheon, and therefore under the immediate influence of food. But towards the end of the inquiry a certain number of experiments were made just before lunch, corresponding with others made after lunch, in order to determine in a general way the effect of a full mid-day meal on the heat-producing power of the body. The mean of seventy-two experiments on four persons, aged respectively 15, 27, 28, and 69, gave 102,907 calories per hour,* and varied from 80,639 to 137,078. In other words, the mean heat given out in one hour was such as would raise 102,907 grams of water by 1° centigrade (from 0° to 1°).

The next point we submitted to enquiry was the relation, if any, between the oxygen absorbed from the air breathed, and the calories emitted at the same time.

The oxygen absorbed was determined by collecting the air expired by the person in the calorimeter, and estimating the CO_2 and O contained in the expired air. This was done by methods fully described in previous papers (by W. M.), and need not be further insisted upon. We found the method of breathing for collecting the air expired (inspiration through nose and expiration through mouth) quite satisfactory in every way, the subjects for these experiments being all used to this mode of breathing.

It is important to observe at the outset that, while there were great differences between the calories found for each person, the oxygen absorbed from the air in every individual case did not exhibit such marked variations; moreover, except in a very general way, the oxygen absorbed failed to vary in proportion with the number of calories emitted.

* These experiments include the whole number made, most of them under the influence of a full meal, but a few fasting, or before the mid-day meal. Of course they can only be expected to give a general idea of the mean calories emitted by man, as the amount of heat emitted varies with every different person, and under different conditions as to food and many other circumstances.

Calories emitted in one hour and corresponding Oxygen absorbed.
W. M. under experiment. Age 69; weight 57·9 kilograms.

Calories in one hour.	Change of sublingual temperature.	Time for collecting air expired.	O absorbed.	Calories for 1 gram O absorbed.	
	° C.	mins. secs.			
122,124	—	8 2	24·276	5031	4518
110,654	—	7 48	25·592	4324	
94,837	—	7 30	22·581	4200	
93,905	0·0	21 0	24·362	3855	4143
93,408	—	15 24	21·697	4305	
92,731	−0·25	32 28	21·721	4269	
*91,270	−0·2	54 35	24·233	3766	4064
*90,882	—	21 36	22·615	4019	
90,844	+0·1	21 50	20·611	4408	
*90,155	−0·1	24 3	21·764	4142	3938
*89,085	−0·2	20 3	25·015	3561	
89,011	+0·05	15 45	21·643	4113	
88,832	—	24 0	21·961	4045	3969
88,406	0·0	27 43	21·867	4043	
*87,240	−0·3	28 0	22·830	3821	
81,315	−0·15	One hour	23·062	3526	3409
80,639	−0·1	29 29	24·495	3292	
				Mean 4042	
Supplementary List.					
107,397	—				
104,169	—				
101,151	+0·15				
98,123	−0·1				
97,974	—				
96,399	−0·25				
95,598	—				
88,641	—				
87,314	−0·2				

* The figures for calories with an asterisk correspond to experiments made in the calorimeter with an overcoat on. The effect of the increased clothing is insufficient to influence the general means.

Calories emitted in one hour and corresponding Oxygen absorbed.
R. B. F. under experiment. Age 27; weight 53·0 kilograms.

Calories in one hour.	Change of sublingual temperature.	Time for collecting air expired.		O absorbed.	Calories for 1 gram O absorbed.	
	° C.	mins.	secs.			
105,203	0 ·0	26	0	26 ·458	3976	
103,569	—	8	50	23 ·249	4455	4283
103,186	−0 ·05	23	0	23 ·352	4419	
101,445	—	9	10	23 ·266	4360	
100,077	0 ·0	21	0	26 ·785	3736	4161
97,071	—	9	20	22 ·131	4386	
96,947	—	18	0	22 ·286	4350	
95,924	−0 ·3	22	0	23 ·215	4132	4044
92,880	−0 ·05	23	17	25 ·443	3651	
91,622	—	7	40	26 ·312	3482	
91,558	0 ·05	20	0	25 ·951	3528	3796
81,882	−0 ·3	28	0	23 ·533	4379	
80,985	−0·45	15	41	23 ·593	3433	3433
					Mean 4022	
Supplementary List.						
106,839						
102,940						
101,661						
100,159	−0 ·25					
99,309	−0 ·05					
96,735	−0 ·2					
90,523	−0 ·25					
85,338	−0 ·4					

Calories emitted in one hour and corresponding Oxygen absorbed.
E. R. under experiment. Age 28; weight 80·4 kilograms.

Calories in one hour.	Change of sublingual temperature.	Time for collecting air expired.	O absorbed.	Calories for 1 gram O absorbed.
	° C.	mins. secs.		
126,928	+0·1	26 0	30·762	4126
124,335	—	13 45	30·665	4055
117,131	+0·05	28 32	29·290	3990
116,874	−0·3	12 2	30·237	3865
115,221	−0·15	24 41	28·379	4060
111,754	0·0	22 2	32·887	3398
				Mean 3916
Supplementary List.				
137,078	−0·3			
129,028	0·0			
127,594	+0·15			
126,872	+0·1			
125,129	—			

These lists include thirty-six experiments on three different persons, in all of which the oxygen taken from the air, while in the chamber, was determined. At the outset a striking similarity is observed between the *means* of the calories produced for 1 gram of oxygen absorbed.

(Mean of 17 exp.)	With W. M.	that figure is....	4042
(„ 13 „)	„ R. B. F.	„ ...	4022
(„ 6 „)	„ E. R.	„	3916

It is, therefore, obvious that there is a definite relation of cause to effect in the absorption of oxygen towards the production of animal heat. These figures must not be considered as absolutely final; they show that under similar circumstances relating to time of food, &c., the mean calories produced for 1 gram of oxygen absorbed are the same for different persons, at all events as far as can be gathered from the three subjects experimented upon; and, moreover, it may be concluded that the true figure closely approximates 4000 (small calories). Hirn, from his experiments, gives 5·22 large calories for 1 gram of oxygen absorbed, which exceeds our figure (4·00) to a marked extent.

If the volume of oxygen absorbed from the air was proportional to the calories given out during the same time, then, by placing in a tabular form the numbers for the calories found, beginning with the

highest number and ending with the lowest, and also inscribing opposite these figures those showing the oxygen absorbed in each corresponding experiment, it would be expected that the figures for oxygen absorbed would follow in succession those for the calories found, beginning with the highest and ending with the lowest. Such, however, is far from being the case. Therefore, except in a very general way, as shown by our *means* and under similar circumstances with reference to food, the oxygen taken from the air *does not produce heat in the body in proportion to the amount absorbed.* And this may be taken as a clear indication that the oxygen absorbed in a given time is not a measure of the heat produced during that same time.

Should tables now be made of the calories in numerical order, beginning with the highest, placing the figure for "calories for 1 gram oxygen absorbed" opposite its respective calories, a peculiar occurrence is observed. It will be seen readily by a consideration of the foregoing tables that if the calories found in one hour and those calculated for 1 gram oxygen absorbed be grouped three by three (or even two by two), the calories for 1 gram oxygen absorbed decrease fairly regularly together with the falling for the hour-calories (less so when taken two by two), and this takes place in the case of three different persons, and therefore cannot possibly be accidental. It follows that 1 gram of oxygen absorbed from the air is attended with the emission of either 5031 calories or 3292 calories, as extremes for one person, and for another person either 4455 or 3433 calories, and again for a third either 4126 or 3398 calories. The readiest explanation of this phenomenon is the assumption of a storage of oxygen in the tissues, which is made use of, although unaccounted for (as oxygen absorbed) at the time. Still, the *mean* relation of the oxygen absorbed to the heat emitted remains the same, being as nearly as possible 4000 calories for 1 gram oxygen absorbed under similar conditions.

This shows that whatever be the mode of action of the absorbed oxygen it repeats itself in a general way, if taken at similar periods with reference to food, &c.

There is a circumstance in these experiments which should be taken into account concerning the frequent change of temperature of our bodies while in the calorimeter, as ascertained by sublingual observations with a clinical thermometer. The cooling reached an extreme of 0·45° C., though usually only 0·15° or 0·2° C., but it varied much in different experiments, while on some occasions there was no change, and even once or twice a rise was observed. The fall of temperature was thought at first to be due to the proximity of the ice in the chamber; but the same effect was observed by taking W. M.'s sublingual temperature while sitting quite quiet for an hour

out of the calorimeter, when a distinct and gradual fall in the sublingual temperature occurred to the extent of 0·2° C.

We looked carefully through the results obtained, in order to ascertain whether this cooling of the body while under experiment had any appreciable influence either on the heat emitted, or on the oxygen absorbed, but failed to observe any phenomena which might be ascribed to such a cause; it must, however, be attended with some effect.

A few experiments were made on the influence of food in a general way by comparing the heat given out in the calorimeter by the same individual, shortly before, and one or two hours after the midday meal, the meal consisting of a full allowance of meat, potato, bread, and a glass of beer. The experiments before luncheon are, therefore, in a comparatively fasting condition, and those after luncheon may be looked upon as being under the influence of a full meal.

Before lunch.	After lunch.	Per cent. increase after lunch.
	W. M.	
92,731	96,399	3·95
88,406	98,123	10·99
(90,844	87,314	fall)
81,315	101,151	24·39
	R. B. F.	
95,924	99,309	3·53
81,882	84,653	3·38
80,985	91,208	12·62
96,050	99,474	3·56
	E. R.	
111,754	125,129	11·97
115,221	126,872	10·11
116,874	129,028	10·40
117,131	127,594	8·93
126,928	135,870	7·04
	E. F.	
(118,087	114,377	fall)
121,868	125,001	2·57
(114,675	110,495	fall)
98,643	109,730	11·24
104,922	108,952	3·84
109,078	112,780	3·39
667,273	681,335	

Therefore out of nineteen experiments only three show a fall in the amount of heat emitted after lunch. Of these three, one (W. M.) is easily accounted for from the digestion of the person under experiment being on that day somewhat out of order, and very little food being taken. In the other instances, in which the laboratory boy was in the calorimeter, he acknowledged finding it difficult to sit quiet, and movement may easily account for the irregular result.

It follows from these experiments that the rule is an increase in the emission of heat from the body after a full meal.

Finally it was of interest to ascertain how far the heat emitted by the body is in proportion to the weight of the body. The following table shows clearly that this relation is subject to great variations; the lightest person under experiment, also the youngest (being sixteen years of age), gave out a mean amount of heat per kilo. weight greatly exceeding all the others.

	Calories per hour.	Weight of the body.	Mean calories per kilogram.
W. M. (mean of 26 experiments)...	95,605	57·9	1651
R. B. F. „ 21 „ ...	96,469	53·0	1820
E. R. „ 11 „ ...	123,449	80·4	1535
E. F. „ 12 „ ...	112,217	41·0	2737

When the work connected with this paper was nearly completed, it occurred to us that there were two important omissions in the enquiry. The first was the neglect to take into account the heat lost from the calorimeter by the air expired when it was collected for analysis; * on the other occasions the air was expired into the calorimeter, and therefore there was no loss of heat from that cause. We now made a few experiments, taking the temperature of the air expired at its exit from the chamber. The excess of this temperature over that of the air inspired was used for calculating the heat lost, and the correction introduced where necessary. This figure varied somewhat for each person under experiment. The second omission was leaving the carbonic acid which might have collected

* Supposing the air expired was found on its exit from the calorimeter to be 8° C. higher than the external air, and that this volume of air reduced amounted to 112·5 litres in 25 minutes, this would give a weight of 145·5 grams of air, which multiplied by the specific heat of air (0·2375) and by 8, the excess temperature = 276·4 calories, or for an hour 663 calories. On a total heat of 95,000 calories, the heat thus lost would only amount to 0·7 per cent.

in the calorimeter unaccounted for. Some CO_2 must be derived from the skin, and perhaps some small quantity of air might possibly have escaped from the face-piece into the chamber.

The calorimeter was conveniently available for the determination of the CO_2, which might have collected in it, as the chamber was perfectly closed, whatever minute openings there were being much too small to allow of any diffusion out of the chamber. This was tested experimentally in the course of the present enquiry by expiring air into the bell-jars, while out of the calorimeter; shortly afterwards the same person entered the chamber and breathed in it for forty minutes or an hour. The mean of eight experiments gave figures for the CO_2 in and out of the chamber exactly the same.*

The determination of the CO_2 in the air of the chamber while breathing the external air was made by putting on the face-piece on entering the calorimeter, and after the door was closed, rinsing a dry flask (holding about 6 litres) with air from the upper agitator; this flask was then stopped with an india-rubber cork, having a tube with a stopcock inserted through it. After sixty minutes another large, dry flask, full of fine, dry sand, was suddenly emptied of its contents, and closed with a cork similar to that used with the other flask. The determination of CO_2 was made in each flask with a standard solution of barium hydrate, by Pettenkofer's method. The CO_2 in the chamber was obtained by subtracting the weight (or volume) of CO_2 found in the chamber at the very beginning of the experiment from the weight of the CO_2 found in the chamber after the subject had remained an hour in it. This CO_2 varied somewhat with the three persons who submitted to experiment; the mean value for each of us was used for the correction of the oxygen absorbed; this correction was, however, but small, varying from about 1 to 3 per cent. of the CO_2 determined in the air collected in the bell-jar.

The results obtained from the present enquiry may be summarised as follows:—

1. The amount of heat given out from the human body when

*

CO_2 in bell-jars per minute.	Time for collecting in bell-jar.		CO_2 in chamber per minute.
c.c.	Mins.	Secs.	c.c.
204·4	9	20	199·2
181·5	8	3	176·1
176·0	9	16	183·5
208·6	7	41	214·6
200·1	8	25	194·7
187·9	8	31	200·2
205·0	8	50	194·9
194·8			194·7

tested on two successive half-hours is found to be the same when the means of the calories are taken, although in each separate experiment the heat emitted may vary to some slight extent.

2. The heat emitted by the same person varies, and the extent of this variation is wider in some subjects than in others; thus in W. M.'s case the calories emitted in one hour from twenty-six experiments varied from 122,124 to 80,639, or by 33·9 per cent. of the larger figure. In the twenty-one experiments of R. B. F. they varied from 106,839 to 80,985, or by 24·2 per cent. With E. R., in eleven experiments, from 137,078 to 111,754, or by 18·5 per cent.

3. As a fact irrespective of theory the mean number of calories found from three different persons, under similar circumstances of food, &c., corresponding to 1 gram of oxygen absorbed from the air, was the same, and can be stated in round numbers at 4000. Had more experiments been done fasting, this figure would have shown a slight tendency to fall.

4. Although the *mean* calories per individual for 1 gram oxygen absorbed under similar circumstances of food, &c., are the same, still in the experiments taken singly, the number of calories corresponding to 1 gram oxygen absorbed, vary, and this in a regular way. The greater the heat given out, the greater the calories produced for 1 gram oxygen absorbed, and *vice versâ*. Therefore, either a given amount of oxygen absorbed can produce different quantities of heat, or the oxygen found as absorbed does not represent that to which the heat is due; this second alternative appears the more probable.

5. The influence of a meal, as ascertained on three different persons, is well marked. Taking the midday meal, when mixed food is eaten, generally with a good appetite, the calories emitted about two hours after lunch show an increase over those given out about three or four hours after breakfast. The excess varies in different persons, and according to the kind and amount of food taken.

6. The calories emitted per kilo. weight of the body are subject to marked variations in different persons.

A few experiments were made on the influence of clothing on the heat emitted, but we thought it best to reserve that subject for a future communication.